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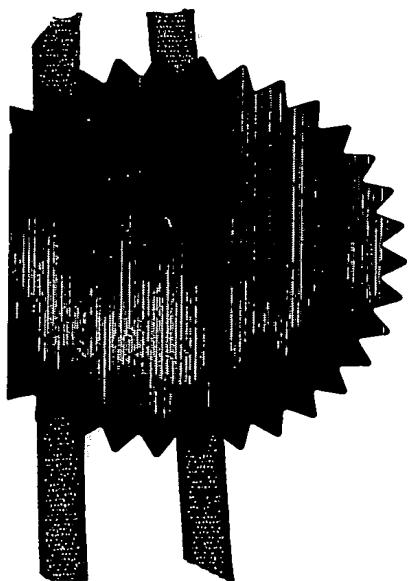
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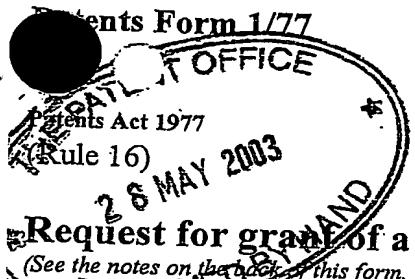
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1/77

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1. Your reference

AWP/P58023/000

2. Patent application number

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0312201.7

28 MAY 2003

3. Full name, address and postcode of the or of each applicant (*underline all surnames*)

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UNITED KINGDOM

Patents ADP number (*if you know it*)

573943502

If the applicant is a corporate body, give the country/state of its incorporation

UNITED KINGDOM

4. Title of the invention

AN ENGINE WITH A PLURALITY OF OPERATING MODES INCLUDING OPERATION BY COMPRESSED AIR

5. Name of your agent (*if you have one*)

BOULT WADE TENNANT

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Description 14

Claim(s) 13

Abstract -

Drawing(s) 2+? *ff*

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Statement of inventorship and right to grant of a patent (*Patents Form 7/77*)

Request for preliminary examination and search (*Patents Form 9/77*) 1

Request for substantive examination (*Patents Form 10/77*) YES

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11

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DUPPLICATE

AN ENGINE WITH A PLURALITY OF OPERATING
MODES INCLUDING OPERATION BY COMPRESSED AIR

5 The present invention relates to an engine which can run as an internal combustion engine and which can run as a compressor to generate compressed air and which can also use stored compressed air previously generated to power the engine.

10 There has been considerable research into development of a vehicle with an engine which has zero emissions in certain operating conditions, e.g traffic conditions in cities. Much of the research has centred 15 upon using a combination of an internal combustion engine with an electric motor, with the internal combustion engine being used outside cities to generate electricity which is stored for subsequent use in powering the electric motor in city use of the 20 vehicle. When the electric motor is running alone there are zero emissions.

25 The present invention tackles the problem of providing an engine which can operate with zero emissions in a different manner.

30 The present invention in a first aspect provides an engine comprising a variable volume chamber; inlet valve means controlling admission of charge air into the variable volume chamber; fuel delivery means for delivering fuel to be mixed with the charge air admitted to the variable volume chamber; and exhaust 35 valve means for controlling exhaust to atmosphere from the variable volume chamber of combusted gases resulting from combustion in the variable volume

chamber of the fuel with the admitted charge air; wherein: the engine has a first operating mode in which the inlet valve means admits charge air into the variable volume chamber, the fuel delivery means
5 delivers fuel which is mixed with the admitted charge air, the mixture of fuel and charge air is compressed by the variable volume chamber reducing in volume, the compressed mixture of fuel and air combusts, the combusted gases expand and force the variable volume
10 chamber to increase in volume and the expanded combusted gases are exhausted to atmosphere from the variable volume chamber via the exhaust valve means; characterised in that: the engine additionally comprises a reservoir for storing compressed air which
15 is connected to the variable volume chamber; and gas flow control valve means controlling flow of air between the variable volume chamber and the reservoir for storing compressed air; and characterised in that the engine has at least two additional operating
20 modes: a second operating mode in which the inlet valve means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the gas flow control valve means allows the compressed air to
25 flow from the variable volume chamber to the reservoir to be stored therein; and a third operating mode in which the gas flow control valve means allows compressed air to flow from the reservoir into the variable volume chamber and thereafter expand to force
30 the variable volume chamber to increase in volume, the expanded air subsequently being exhausted to atmosphere.

The present invention in a second aspect provides
35 an engine comprising a plurality of variable volume

chambers; inlet valve means controlling admission of charge air into the variable volume chambers; fuel delivery means for delivering fuel to be mixed with the charge air admitted to the variable volume
5 chambers; and exhaust valve means for controlling exhaust to atmosphere from the variable volume chambers of combusted gases resulting from combustion in the variable volume chambers of the fuel with the admitted charge air; wherein the engine can operate at least one of the plurality of variable volume chambers
10 in a plurality of different operating modes; and the engine can operate each variable volume chamber in a first operating mode in which the inlet valve means admits charge air into the variable volume chamber,
15 the fuel delivery means delivers fuel which is mixed with the admitted charge air, the mixture of fuel and charge air is compressed by the variable volume chamber reducing in volume, the compressed mixture of fuel and air combusts, the combusted gases expand and force the variable volume chamber to increase in
20 volume and the expanded combusted gases are exhausted to atmosphere from the variable volume chamber via the exhaust valve means; characterised in that: the engine additionally comprises: a reservoir for storing
25 compressed air which is connected to at least one of the plurality of variable volume chambers; and gas flow control valve means controlling flow of gas between at least one of the variable volume chambers and the reservoir for storing compressed air; and
30 characterised in that the engine can operate at least one of the plurality of variable volume chambers in at least two additional operating modes: a second operating mode in which the inlet valve means admits charge air into the variable volume chamber, the
35 admitted charge air is compressed by the variable

volume chamber reducing in volume and the gas flow control valve means allows the compressed air to flow from the variable volume chamber to the reservoir to be stored therein; and a third operating mode in which
5 the gas flow control valve means allows compressed air to flow from the reservoir into the variable volume chamber and thereafter expand to force the variable volume chamber to increase in volume, the expanded air subsequently being exhausted to atmosphere.

10

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings in which :

15 Figure 1 is a schematic representation of one cylinder of a multi-cylinder internal combustion engine according to the present invention; and

Figure 2 is a schematic representation of the top surface of the combustion chamber shown in Figure 1.

20 In Figure 1 there is shown a piston 10 which reciprocates in a cylinder 11 and defines therewith a variable volume combustion chamber 12. Two inlet valves 13 and 14 control flow of charge air into the combustion chamber 12. A gas flow control valve 15 controls flow of pressurised air to and from a pressure vessel 16, as will be described later. An exhaust valve 17 controls flow of combusted gases out of the combustion chamber through an exhaust passage 18 which relays the exhausted gases to atmosphere. An injector 33 delivers fuel into the combustion chamber and also comprises a spark plug.
25
30

The four valves 13, 14, 15 and 17 are connected one each to four hydraulic actuators 19, 20, 21 and 22

which open and close the valves 13, 14, 15 and 17 under the control of four electrically operated control valves 23, 24, 25, 26 associated one each with the actuators 19, 20, 21 and 22. Each of the control 5 valves 23, 24, 25, 26 is connected both to a source of pressurised hydraulic fluid 27 (e.g. a pump) and an exhaust for pressurised fluid (e.g. a sump from which fluid is drawn by the pump). The control valves 23, 24, 25, 26 are all controlled by electrical signals 10 produced by an electronic controller 29 which produces control signals having regard to a plurality of engine operating parameters (as sensed by a plurality of sensors, not shown) and having regard to the position of the piston 10 in the cylinder 11 as sensed by a 15 rotation sensor 30 connected to a crankshaft 31 driven to rotate by a connecting rod 32 connected to the piston 10.

Each control valve, e.g. 23, can connect an upper 20 chamber of an associated actuator, e.g. 19, to receive pressurised fluid from the pump 27 whilst at the same time connecting a lower chamber of the associated actuator to return fluid to the sump 28, whereby the relevant valve, e.g. 13, is driven to open. Each 25 control valve, e.g. 23, can also connect a lower chamber of an associated actuator, e.g. 19, to receive pressurised fluid from the pump 27 whilst connecting the upper chamber of the associated actuator to return fluid to the sump 28, whereby the relevant valve, e.g. 30 13, is driven to close.

The engine in which the piston 10 and cylinder 11 are located will have, for instance, three additional cylinders with three additional pistons reciprocating 35 therein, the pistons all connected to the common

crankshaft 31, and each having hydraulically actuated valves as described above, all of the valves being controlled by a common electronic controller 29.

5 The use of the engine described above in an automobile will now be described.

In normal operating conditions each cylinder of the engine will be operated according to a standard four-stroke cycle. In an intake stroke the inlet valves 13 and 14 will be opened to admit a charge air into the combustion chamber with the injector 33 injecting fuel into the admitted air and then the mixture of fuel and air being compressed in a subsequent compression stroke, then ignited by the spark plug 33 and then the ignited gases expanding in a power stroke with the exhaust valve 17 subsequently opened in an exhaust stroke to allow the combusted gases to be expelled from the combustion chamber.

10 Throughout the four-stroke operation the controller 29 keeps the gas control valve 15 closed.

In part load/low load conditions, only two out of the four cylinders will be operated by a standard four-stroke cycle in the manner described above. The other two cylinders, e.g. cylinder 11, will be turned into compressors as now described. First of all, the existence of suitable part-load conditions will be detected by the controller 29 from the various signals received thereby. Then the controller 29 will control the actuators 19, 20, 21, 22 so that in each down-stroke of the piston 10 the inlet valves 13 and 14 are opened to allow air to be drawn into the chamber 12. The injector 33 will be kept inactive so that in each upstroke the piston 10 will pressurise a charge of

pure air in the chamber 12. The controller 29 will then open the gas control valve 15 during the upstroke to allow air pressurised in the chamber 12 to be expelled to the reservoir 16 which stores pressurised air.

When the engine is operated with two cylinders compressing air then the remaining cylinders operating each according to a four-stroke cycle will put work into the cylinders pressuring the air. By making the combustion cylinders work harder their emissions of NOx and hydrocarbons can be improved as compared with the situation in which all the cylinders operate a normal four-stroke cycle at part-load. The electronic controller 29 will evaluate what power output is needed from the engine for a given set of operating conditions and will then determine whether the required power can be provided by operating less than the full number of cylinders.

When the engine is decelerating and engine braking is required, then the electronic controller 29 can switch all the cylinders into a mode in which they operate as compressors as described above, each piston drawing in air in each downstroke and pressurising the air in a subsequent upstroke, with the pressurised air being expelled to the reservoir 16. The momentum of the vehicle will provide the energy for the compression of the air. The compression of the air will absorb the kinetic energy of the vehicle and thus slows the vehicle very effectively.

A pressure sensor 34 measures pressure of gases in the combustion chamber 12. A pressure sensor 35 measures pressure of stored compressed air in the

reservoir 16. The pressure sensors 34 and 35 relay measured signals to the electronic controller 29 and the controller 29 will only open each gas control valve, e.g. 15, when the pressure of the compressed air in the variable volume chamber, e.g. 12, is greater than the pressure in the reservoir 16. When the reservoir 16 is fully pressurised then the electronic controller 29 will keep the gas control valves, e.g. 15, closed and will either keep all of the inlet and exhaust valves of a particular cylinder also closed with air trapped and the variable volume chamber functioning as a gas spring (this being preferable in part-load conditions when e.g. two cylinders are active and two cylinders are deactivated) or alternatively the electronic controller 29 will operate to open the inlet and exhaust valves in order to allow air to be compressed and then the compressed air vented to exhaust (this being preferable during vehicle deceleration conditions). Additionally, the compressed air could be vented to atmosphere via the air intake system under control of the inlet valves, e.g. 13, 14, since it is clean air. This would have the advantage of avoiding passing cool air through a catalytic converter in the engine's exhaust system (which could have the effect of lowering the temperature of the catalytic converter below its working temperature).

It is preferable that the vehicle in which the engine is operating has an automatic gearbox. The transmission will then automatically change to a low or the lowest gear ratio during braking of the vehicle so as to increase the rate of revolution of the engine and thus the work done to compress air and hence the regenerative braking effect. A continuously variable

transmission would be ideal since the gear ratio would be continuously varied with vehicle speed. An electric transmission could be used but any automatic gearbox would suffice.

5

When the engine is working as a compressor during braking then a two-stroke cycle will be used with air being drawn into each working cylinder with each downstroke of the piston in the cylinder and
10 compressed air driven out of each working cylinder with each up stroke of the piston in the cylinder.

10

Once a store of compressed air has been built up in the reservoir 16 then the compressed air can be used to power the engine. Perhaps this can be done when the vehicle is initially started or when the vehicle is crawling along in traffic conditions. In such an operating mode the engine will operate as a pneumatic engine and the controller 29 will keep the inlet valves (e.g. 13,14) of each cylinder closed and will then control the opening and closing of the gas flow control valve 15 and the exhaust valve 17 so that compressed air is admitted into the chamber 12 from the reservoir 16 to force the piston 10 downwardly and then the expanded air is exhausted from the chamber 12 to the exhaust 18 in a subsequent upstroke.
20 Alternatively the clean expanded air could be vented to atmosphere via the air intake system under control of the inlet valves, e.g. 13,14.

25

30

Since the stored energy of the compressed gas will be permanently available it is ideal to use the

compressed gas on starting of the engine in order to start the vehicle in motion. This will help improve emissions because emissions are usually poor during starting of an engine. Furthermore, the stored
5 compressed gas can allow clutchless starting of a vehicle. Whereas an internal combustion engine must be allowed to fire and rotate before it drives the vehicle, the pistons of the engine can be connected to the drive shaft during starting when compressed air is
10 used to drive them and therefore a clutched operation is not necessary.

It is envisaged that when a vehicle moves off from stationary then perhaps the engine will be
15 operated so that it starts in its pneumatic mode and then moves to a part-load condition in which two cylinders are operated pneumatically and the other two operated by a four-stroke internal combustion engine cycle and then all cylinders will be operated in with
20 a four-stroke combustion cycle as the vehicle picks up speed.

With the engine of the present invention it is possible to eliminate the need for engine idling.
25 When a vehicle stops then the engine can stop. When the vehicle needs to start moving again, the engine can be first operated in pneumatic mode, as described above. This can eliminate idling of an engine altogether and this will be very fuel-efficient.

30 The electronic controller 29 will continually monitor the level of stored gas in the reservoir 16 and will alter the operation of the engine to supply compressed gas to the reservoir whenever it is noted
35 that the stored supply is depleted.

It is envisaged that the reservoir 16 will be a light plastic pressure vessel which will contain pressurised air in the range of 10-20 bar. The vessel will be sized to store compressed gas sufficient for a range of 3 to 5 miles of travel of the vehicle. A typical reservoir would store 140 litres of compressed air.

In a modification of the system described above, a secondary pump could be used to increase pressure of the compressed gas from the pressure of 20 bar supplied by the engine operating in pneumatic mode to a pressure of 200 bar. However, this would involve additional complexity in that there would have to be a heavier storage vessel (e.g. steel) and a separate compressor driven by the engine would have to be used.

As an alternative to use of a secondary pump to boost air pressure after the air is output from the cylinders, an engine-driven supercharger (or an electrically-driven supercharger) could be used to compress air before it is compressed in a cylinder of the engine.

In the above description of the engine operating when powered by compressed air, each working cylinder has been described as operating a two-stroke cycle, with compressed air expanding with each downstroke of a piston in a working cylinder and expanded air expelled with each upstroke of a piston of a working cylinder. However, a four-stroke cycle could be used in which for each working cylinder the inlet valves open for an intake stroke, the charge of air introduced via the inlet valves is then compressed in a compression stroke and then pressurised air is

introduced into the working cylinder in a power stroke and expanded. Finally, the expanded air is exhausted from the working cylinder in an exhaust stroke, either to exhaust via the exhaust valve or to the intake system via the intake valve(s). The use of a four-stroke cycle could increase efficiency of the engine.

The pressurised air stored in the reservoir could be combusted in the cylinders rather than expanded in them, provided that a direct fuel injection system is used in which fuel is delivered directly to a working cylinder to be mixed with air in the cylinder. This has the capability of enhancing performance from a standing start of a vehicle powered by the engine of the present invention. Also, if the engine is turbocharged then the use of pressurised air from the reservoir can reduce the lag typical with turbocharged engines. To permit this possibility the engine will need to be operable with a four-stroke cycle in which in each intake stroke charge air is introduced into a cylinder via the gas control valve from the reservoir of pressurised air. The complete charge could be supplied from the reservoir or alternatively the inlet valves could be opened for the start of an intake stroke and then closed with the gas control valve opening in the latter part of the intake stroke to introduce air at boost pressure. The inlet valves and the gas control valve will not be opened simultaneously. When all of the charge air is supplied from the reservoir of pressurised air then the inlet valves will remain closed throughout the whole of each intake stroke.

With a multi-cylinder engine it may be possible

to achieve double (or triple) compression and expansion. If the cylinders are connected together in a suitable way by conduits external to them then air could be compressed in a first cylinder to first level, then compressed in a second cylinder to a second higher level and then compressed in a third cylinder to a higher level still. Similarly, compressed air from the reservoir could be expanded in one cylinder to a first degree and then expelled with the expelled air expanded again in another cylinder to a second higher degree and finally with the twice-expelled air expanded once more to a third degree in a further cylinder. This will only be possible in engines which have pistons phased in motion relative to each other in a particular way, but will raise efficiency where possible.

Whilst above the invention is described in the implementation in a piston engine, the invention could also be used in any rotary device, e.g. a rotary engine (such as a Wankel engine) or any other engine with a variable volume chamber can be used either as a combustion chamber or a compression chamber. Thus references to "strokes" in the description and claims should, in the case of e.g. a rotary engine, be understood to include references to increasing periods of increasing volume of a chamber and periods of decreasing volume of a chamber in engines which do not have a piston sliding in a cylinder. A "downstroke" should be understood to include an increasing volume period for a variable volume chamber in an engine without a piston. An "upstroke" should be understood to include a decreasing volume period in an engine without a piston.

35

Comparing a vehicle driven by the engine of the

present invention with a vehicle driven by a combination of an internal combustion engine and electric motor, the present invention has the advantage of simplicity. There is no need for an electrical generator or for an electrical motor or for battery storage. Each of these items are also quite expensive and therefore the present invention has the advantage of low cost.

CLAIMS

1. An engine comprising:
a variable volume chamber;
5 inlet valve means controlling admission of charge air into the variable volume chamber;
fuel delivery means for delivering fuel to be mixed with the charge air admitted to the variable volume chamber; and
10 exhaust valve means for controlling exhaust to atmosphere from the variable volume chamber of combusted gases resulting from combustion in the variable volume chamber of the fuel with the admitted charge air; wherein:
15 the engine has a first operating mode in which the inlet valve means admits charge air into the variable volume chamber, the fuel delivery means delivers fuel which is mixed with the admitted charge air, the mixture of fuel and charge air is compressed by the variable volume chamber reducing in volume, the compressed mixture of fuel and air combusts, the combusted gases expand and force the variable volume chamber to increase in volume and the expanded combusted gases are exhausted to atmosphere from the variable volume chamber via the exhaust valve means;
20 characterised in that the engine additionally comprises:
25 a reservoir for storing compressed air which is connected to the variable volume chamber; and
30 gas flow control valve means controlling flow of air between the variable volume chamber and the reservoir for storing compressed air;
and characterised in that the engine has at least two additional operating modes:
35 a second operating mode in which the inlet valve

means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the gas flow control valve means allows the compressed air to flow from the variable volume chamber to the reservoir to be stored therein; and

5 a third operating mode in which the gas flow control valve means allows compressed air to flow from the reservoir into the variable volume chamber and
10 thereafter expand to force the variable volume chamber to increase in volume, the expanded air subsequently being exhausted to atmosphere.

2. An engine as claimed in claim 1 wherein the
15 expanded air is exhausted to atmosphere via the exhaust valve means.

3. An engine as claimed in claim 1 wherein the expanded air is exhausted to atmosphere via the inlet
20 valve means.

4. An engine as claimed in any one of claims 1 to 3 which has a fourth operating mode in which the inlet valve means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the exhaust valve means allows the compressed air to be exhausted to atmosphere.

25 30 5. An engine as claimed in any one of claims 1 to 3 which has a fourth operating mode in which the inlet valve means admits charge air into the variable volume chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the

inlet valve means allows the compressed air to be exhausted to atmosphere.

6. An engine as claimed in claim 4 or claim 5, which
5 has a fifth operating mode in which: air or combusted gases is/are trapped in the variable volume chamber by closing all of the inlet valve means, the exhaust valve means and the gas flow control valve means, and in which the variable volume chamber with the trapped
10 air or combusted gases operate(s) as a gas spring.

7. An engine as claimed in claim 6, wherein the fuel delivery means is deactivated whilst the engine is operating in the fifth operating mode.
15

8. An engine as claimed in any one of claims 4, 5, 6 or 7 wherein the fuel delivery means is deactivated whilst the engine is operating in the fourth operating mode.
20

9. An engine as claimed in any one of claims 1 to 3 which has a fourth operating mode in which the gas flow control valve means admits compressed air to flow from the reservoir into the variable volume chamber in an intake stroke of the engine for mixing with fuel delivered by the fuel delivery means, with the mixture of fuel and compressed air being further compressed by the variable volume chamber reducing in volume and the further compressed mixture combusting and subsequently expanding to cause the variable volume chamber to increase in volume and with the expanded combusted gases exhausted to atmosphere via the exhaust valve means.
25
30

35 10. An engine as claimed in claim 9 wherein in the

fourth operating mode during the intake stroke of the engine the inlet valve means opens to allow charge air to be drawn into the variable volume chamber during an initial part of the intake stroke and then the inlet 5 valve means closes and subsequently the gas flow control valve mans opens to admit the compressed air into the variable volume chamber to be mixed with the air previously admitted via the inlet valve means.

10 11. An engine as claimed in any one of the preceding claims wherein when the engine is operating in the third operating mode then the engine can operate a two-stroke cycle with the gas flow control valve means admitting compressed air into the variable volume 15 chamber during each downstroke.

12. An engine as claimed in claim 11 wherein when the engine is operating in the third operating mode then the engine can operate a four-stroke cylinder with an 20 intake stroke in which the inlet valve means allows fresh charge air to be drawn into the variable volume chamber, a compression stroke in which the charge air admitted via the inlet valve means is compressed, a power stroke in which the gas flow control valve means 25 admits compressed air into the variable volume chamber to supplement the air previously compressed in the compression stroke and an exhaust stroke in which expanded air is expelled from the variable volume chamber.

30 13. An engine as claimed in any one of the preceding claims wherein the fuel delivery means is deactivated whilst the engine is operating in the second operating mode.

35 14. An engine as claimed in any one of the preceding

claims wherein the fuel delivery means is deactivated whilst the engine is operating in the third operating mode.

5 15. An engine as claimed in any one of the preceding claims wherein the air compressed in the variable volume chamber in the second operating mode of the engine is compressed to a pressure in the range 10 to 20 bar.

10

16. An engine as claimed in any one of the preceding claims wherein the reservoir comprises a light plastic pressure vessel.

15 17. An engine as claimed in any one of claims 1 to 15 comprising additionally a pump powered by the engine which receives compressed air expelled from the variable volume chamber and compresses the air further before the compressed air is delivered to the
20 reservoir.

18. An engine as claimed in claim 10 wherein the pump raises the pressure of the compressed air from an initial pressure in the range 10 to 20 bar to a higher
25 pressure of 100 to 100 bar.

19. An engine as claimed in any one of claims 1 to 15 comprising additionally an engine-driven supercharger which pressurises the charge air admitted into the
30 variable volume chamber via the inlet valve means.

20. An engine as claimed in any one of claims 1 to 15 comprising additionally an electrically-driven turbocharger which pressurises the charge air admitted into the variable volume chamber via the inlet valve
35 means.

21. An engine as claimed in claims 17 to 20 wherein the reservoir comprises a steel pressure vessel.

5 22. An engine as claimed in any one of the preceding claims, wherein the variable volume chamber is defined between a piston and a surrounding cylinder, the piston reciprocating in the cylinder and the piston being connected to a crankshaft of the engine.

10 23. An engine as claimed in any one of the preceding claims wherein each of the inlet valve means, the exhaust valve means and the gas flow control valve means comprises a valve operated by a hydraulic actuator individual to the valve and all of the 15 hydraulic actuators are controlled by a common electronic controller, the electronic controller receiving signals from a plurality of sensors and the electronic controller varying operation of the hydraulic actuators and thereby operation of the 20 valves in order to switch operation of the engine between the operating modes thereof.

25 24. A vehicle comprising an engine as claimed in claim 23 wherein the plurality of sensors includes sensors measuring parameters relating to motion of the vehicle and a sensor measuring pressure of air stored in the reservoir and wherein the electronic controller on detecting that the vehicle is decelerating whilst the reservoir is depleted varies operation of the 30 hydraulic actuators so that the engine operates in the second operating mode.

35 25. A vehicle as claimed in claim 24 which has an automatic transmission with a variable gear ratio and wherein the electronic controller controls the

transmission to lower the gear ratio when the vehicle is decelerating in order to increase revolutionary speed of the engine.

5 26. A vehicle comprising an engine as claimed in claim 24 or 25 wherein the plurality of sensors includes sensors measuring parameters relating to motion of the vehicle and a sensor measuring pressure of air stored in the reservoir and the electronic controller on detecting that the valve is decelerating whilst the reservoir is full varies operation of the hydraulic actuators so that the engine operates in the fourth operating mode.

10 10 26. A vehicle comprising an engine as claimed in claim 24 or 25 wherein the plurality of sensors includes sensors measuring parameters relating to motion of the vehicle and a sensor measuring pressure of air stored in the reservoir and the electronic controller on detecting that the valve is decelerating whilst the reservoir is full varies operation of the hydraulic actuators so that the engine operates in the fourth operating mode.

15 15 27. A vehicle comprising an engine as claimed in claim 24 wherein the plurality of sensors includes sensors measuring parameters relating to motion of the vehicle and to requirements of a driver and the electronic controller on detecting that the vehicle is

20 20 stationary and the driver wishes the vehicle to start moving controls operation of the hydraulic actuators so that the engine operates initially in the third operating mode and then, as speed of the vehicle increases, the operation of the hydraulic actuators is varied so that the engine switches to the first operating mode.

25 25 28. A vehicle as claimed in claim 27 wherein the vehicle commences motion without use of a clutch.

30 30 29. An engine comprising:
 a plurality of variable volume chambers;
 inlet valve means controlling admission of charge air into the variable volume chambers;
 fuel delivery means for delivering fuel to be

mixed with the charge air admitted to the variable volume chambers; and

5 exhaust valve means for controlling exhaust to atmosphere from the variable volume chambers of combusted gases resulting from combustion in the variable volume chambers of the fuel with the admitted charge air; wherein

10 the engine can operate at least one of the plurality of variable volume chambers in a plurality of different operating modes; and

15 the engine can operate each variable volume chamber in a first operating mode in which the inlet valve means admits charge air into the variable volume chamber, the fuel delivery means delivers fuel which is mixed with the admitted charge air, the mixture of fuel and charge air is compressed by the variable volume chamber reducing in volume, the compressed mixture of fuel and air combusts, the combusted gases expand and force the variable volume chamber to increase in volume and the expanded combusted gases 20 are exhausted to atmosphere from the variable volume chamber via the exhaust valve means;

characterised in that:

the engine additionally comprises:

25 a reservoir for storing compressed air which is connected to at least one of the plurality of variable volume chambers; and

30 gas flow control valve means controlling flow of gas between at least one of the variable volume chambers and the reservoir for storing compressed air;

and characterised in that the engine can operate at least one of the plurality of variable volume chambers in at least two additional operating modes:

35 a second operating mode in which the inlet valve means admits charge air into the variable volume

chamber, the admitted charge air is compressed by the variable volume chamber reducing in volume and the gas flow control valve means allows the compressed air to flow from the variable volume chamber to the reservoir to be stored therein; and

a third operating mode in which the gas flow control valve means allows compressed air to flow from the reservoir into the variable volume chamber and thereafter expand to force the variable volume chamber to increase in volume, the expanded air subsequently being exhausted to atmosphere.

30. An engine as claimed in claim 29 wherein in the third operating mode the expanded air is exhausted to atmosphere via the exhaust valve means.

15 31. An engine as claimed in claim 29 wherein in the third operating mode the expanded air is exhausted to atmosphere via the inlet valve means.

20 32. An engine as claimed in any one of claims 29 to 31 wherein the engine can simultaneously operate a first of the variable volume chambers according to the first operating mode while operating a second of the variable volume chambers according to the second operating mode whereby some of the work derived from the expansion of the combusted gases in the first variable volume chamber is used to compress air in the second variable volume chamber.

25 33. An engine as claimed in any one of claims 29 to 32 wherein each variable volume chamber is defined between a stationary element and a movable element and all of the movable elements are connected to a common

power output mechanism whereby work derived from expansion of combusted gases can be output from the engine and also transferred between the movable elements.

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34. An engine as claimed in claim 33 wherein the stationary elements are cylinders in a cylinder block and the movable elements are pistons which reciprocate one in each of the cylinders and the power output mechanism comprises a crankshaft to which all of the pistons are connected.

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35. An engine as claimed in any of claims 29 to 34 wherein each of the inlet valve means, the exhaust valve means and the gas flow control valve means comprises a valve operated by a hydraulic actuator individual to the valve and all of the hydraulic actuators are controlled by a common electronic controller, the electronic controller receiving signals from a plurality of sensors and varying operation of the hydraulic actuators and thereby the valves in order to control the mode of operation of each variable volume chamber of the engine.

25

36. An engine as claimed in claim 35 wherein the plurality of sensors includes sensors measuring parameters relating to load on the engine and a sensor measuring pressure of air stored in the reservoir and the electronic controller on detecting that the engine is part loaded and that the reservoir is depleted controls operation of the hydraulic actuators so that at least a first variable volume chamber is operating in the first operating mode and delivering power output from the engine and at least a second variable volume chamber is operating in the second operating

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35

mode and compressing air for delivery to the reservoir.

37. An engine as claimed in claim 35 wherein the plurality of sensors includes sensors measuring parameters relating to load on the engine and a sensor measuring pressure of air stored in the reservoir and the electronic controller on detecting that the engine is part loaded and that the reservoir is full controls operation of the hydraulic actuators so that first variable volume chamber is operating in the first operating mode and delivering power output from the engine and at least a second variable volume chamber is deactivated by closing the inlet valve means, the exhaust valve means and the gas flow control valve means specific thereto with air or combusted gases trapped in the second variable volume chamber which thereby functions as a gas spring.
38. An engine as claimed in any one of claims 29 to 31 wherein the plurality of variable volume chambers are interconnected by conduit means and when the engine is operating in the second operating mode then the admitted charge air admitted into the said variable valve chamber and compressed therein when allowed to flow from the chamber by the gas flow control volume means flows to at least a second variable valve chamber in which the air is compressed further before flowing to the variable volume chamber to be stored therein.
39. An engine as claimed in any one of claims 29 to 31 wherein the plurality of variable volume chambers are interconnected by conduit means and when the engine is operating in the third operating mode then

the air expanded in said variable volume chamber is exhausted via the exhaust means to at least a second variable volume chamber for further expansion therein before the air is exhausted to atmosphere.

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40. A method of operating an engine which has a plurality of variable volume chambers each defined by a piston reciprocating in a cylinder, the pistons being connected to a common mechanism for delivering power output from the engine, the method comprising 10 operating the engine in a plurality of different modes of operation including:

15 a first operating mode in which a mixture of fuel and air is combusted in each variable volume chamber with expansion of combusted gases forcing the pistons to move and with the expanded combusted gases exhausted to atmosphere;

20 the method being characterised by:
a second operating mode in which a mixture of fuel and air is combusted in at least a first variable volume chamber with expansion of combusted gases forcing the relevant piston to move and with the expanded combusted gases exhausted to atmosphere and in which in at least a second variable volume chamber 25 air is compressed and then the compressed air is delivered to and stored in a reservoir of compressed air; and

30 a third operating mode in which compressed air stored in the reservoir is admitted into at least one variable volume chamber and the admitted compressed air allowed to expand with the expanded air then exhausted to atmosphere.

35 41. A method as claimed in claim 40 wherein in the first operating mode a four-stroke cycle is

implemented.

5 42. A method as claimed in claim 40 or claim 41
wherein in the third operating mode a two-stroke cycle
is implemented.

10 43. A method as claimed in any one of claims 40 to 42
wherein the engine is operated in the first operating
mode at high loads and in the second operating mode at
part loads.

15 44. A method as claimed in any one of claims 40 to 43
wherein the engine is started with the engine
operating according to the third operating mode and
subsequently the operating mode is switched to the
first or second operating mode.

20 45. An engine substantially as hereinbefore described
with reference to and as shown in the accompany
drawings.

FIG. 1.

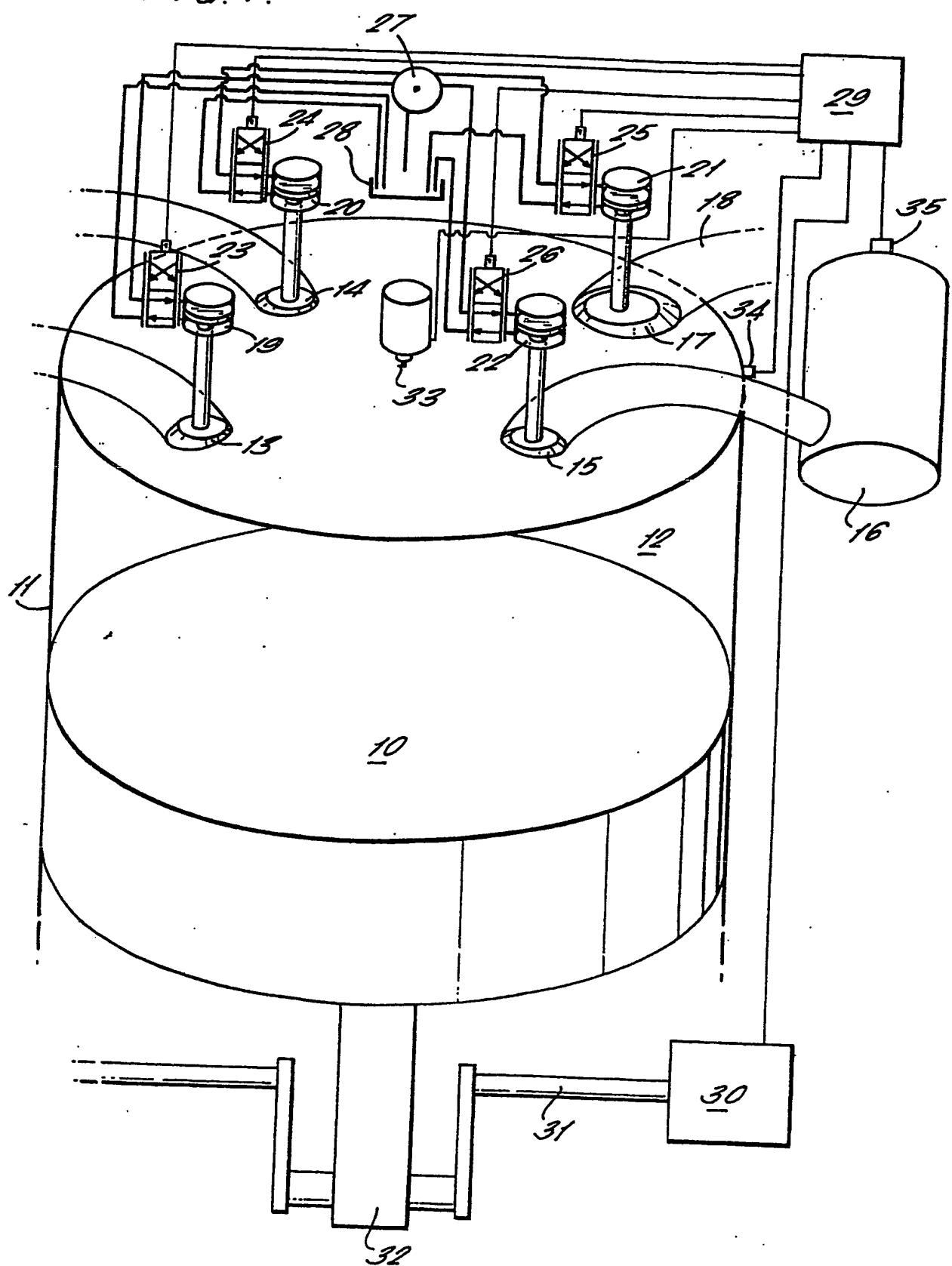
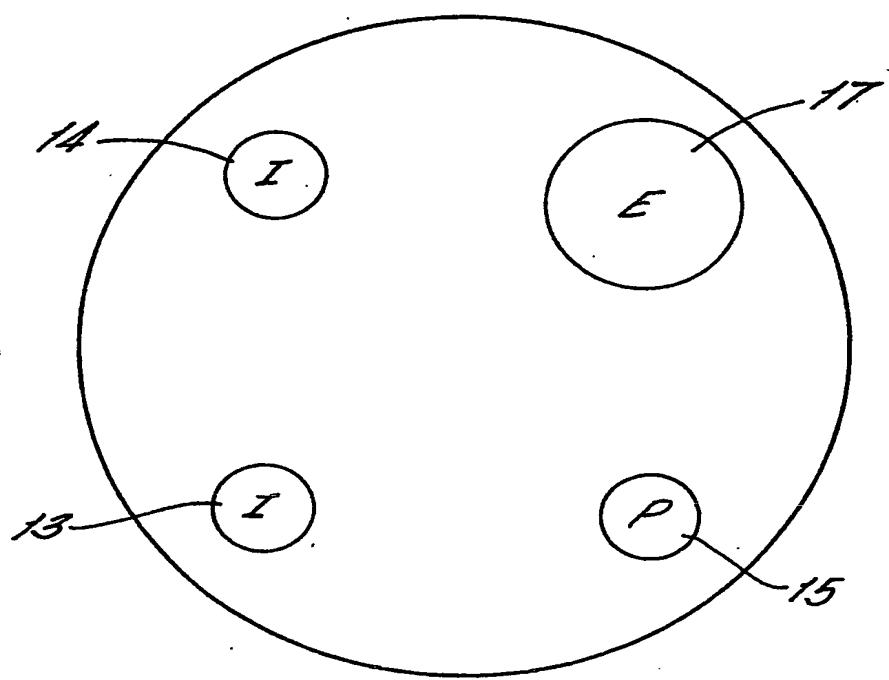


FIG. 2.



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